Long-term Trend of Aerosol Optical Thickness in Support of Studying Solar Dimming and Brightening

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Outline

- Background
- Objectives
- Long-term AVHRR Satellite Aerosol Products and Examples
- Aerosol Optical Thickness (AOT) Trend Analyses and Results
- Summary and Conclusions
- Acknowledgement

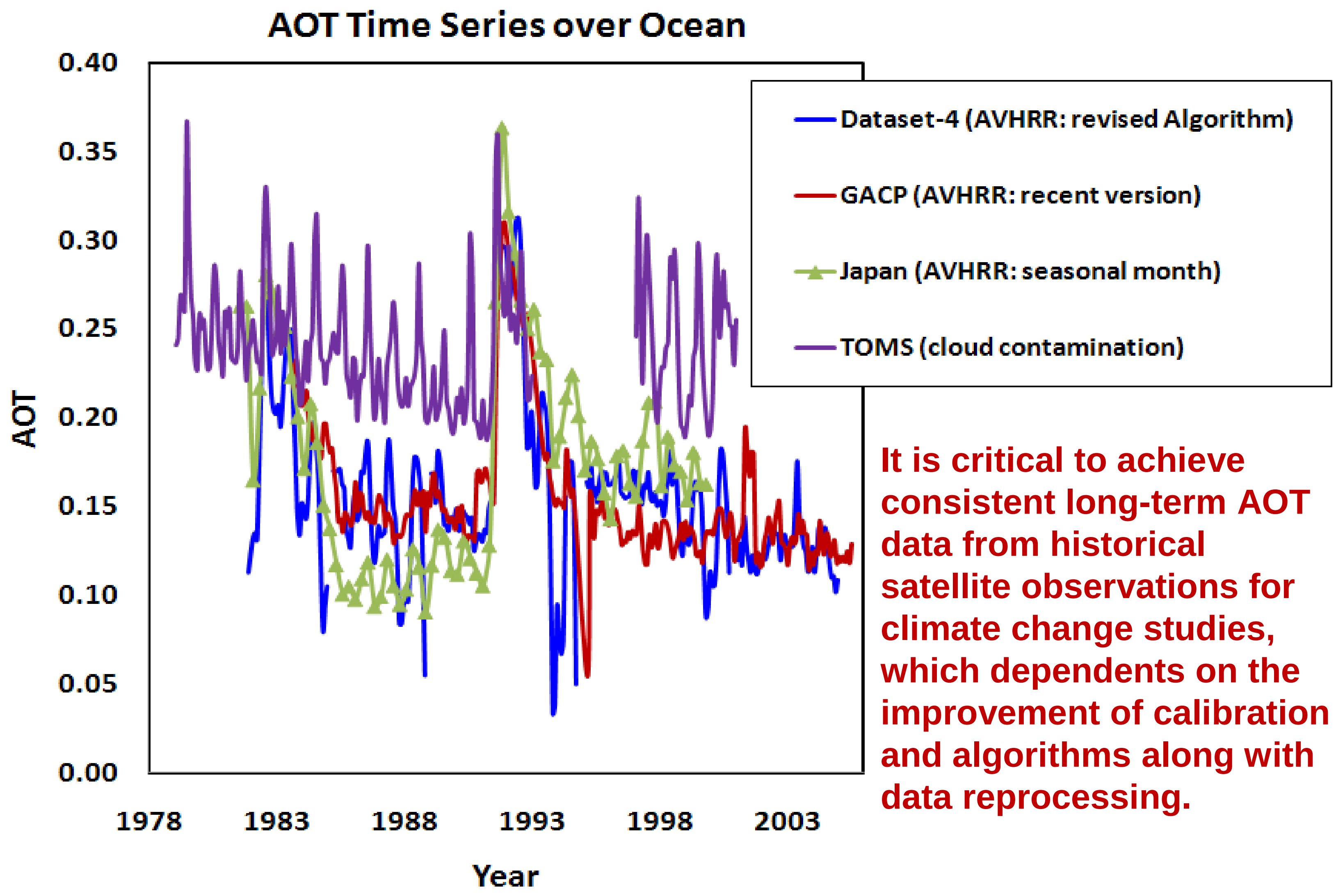
Background

- Aerosols are one of the most important modulators of the solar radiation reaching the Earth's surface (called surface solar radiation (SSR)). There is increasing evidence the SSR has undergone climatologically significant decadal variations in many regions of the world, known as solar dimming/brightening [e.g., Ohmura, 2009; Wild, 2009]

- The causes of the decadal variations in SSR observed in different regions of the world have been studied in relation to the long-term changes of its primary modulators, such as aerosols [e.g., Qian et al., 2007; Riihimaki et al, 2009].

- Satellite observations have been considered as an unique tool for global long-term observation of aerosols [King et al., 1999; Kaufman et al., 2002]. It is compelling to use satellite observations determining if there is any trend in aerosol loading to support the study of SSR decadal variations in different regions of the world .

Aerosol Optical Thickness (AOT) Time Series from Historical Long-term Satellite Observations



It is critical to achieve consistent long-term AOT data from historical satellite observations for climate change studies, which dependents on the improvement of calibration and algorithms along with data reprocessing.

Objectives

- Construct long-term consistent aerosol optical thickness (AOT) climate data record (CDR) over the global ocean by using long-term operational AVHRR satellite observations.
- Analyze AOT long-term trend over the global ocean and selected oceanic regions to support the study of decadal variations of surface solar radiation (SSR).

AVHRR Satellite AOT Products

NOAA/NCDC AVHRR PATMOS-x Based AOT Data Products

Datasets	Products	Retrieval Resolution	Time Coverage	Algorithm	Notes
1	τ_1	Pixel level (GAC data)	1981-2001	One-channel	PATMOS, Old Calibration
2	τ_1 and τ_2	Pixel level (GAC data)	1981-2004	Two-channel	PATMOS-x, with SNO Calibration
3	τ_1 and τ_2	Grid level (0.5°x0.5°)	1981-2004	Two-channel	PATMOS-x based, with SNO Calibration
4 (reference)	τ_1 and τ_2	Grid level (0.5°x0.5°)	1981-2004-2009	Revised Two-channel	PATMOS-x based, with SNO Calibration
5	τ_1	Grid level (0.5°x0.5°)	1981-2004	One-channel	PATMOS-x based, with SNO Calibration

Sensitivity Study Cases

Case 1 (Dataset 2 & 3 Comparison):

Effect of spatial resolution on AOT trend (orbital pixel level versus orbital grid level retrieval).

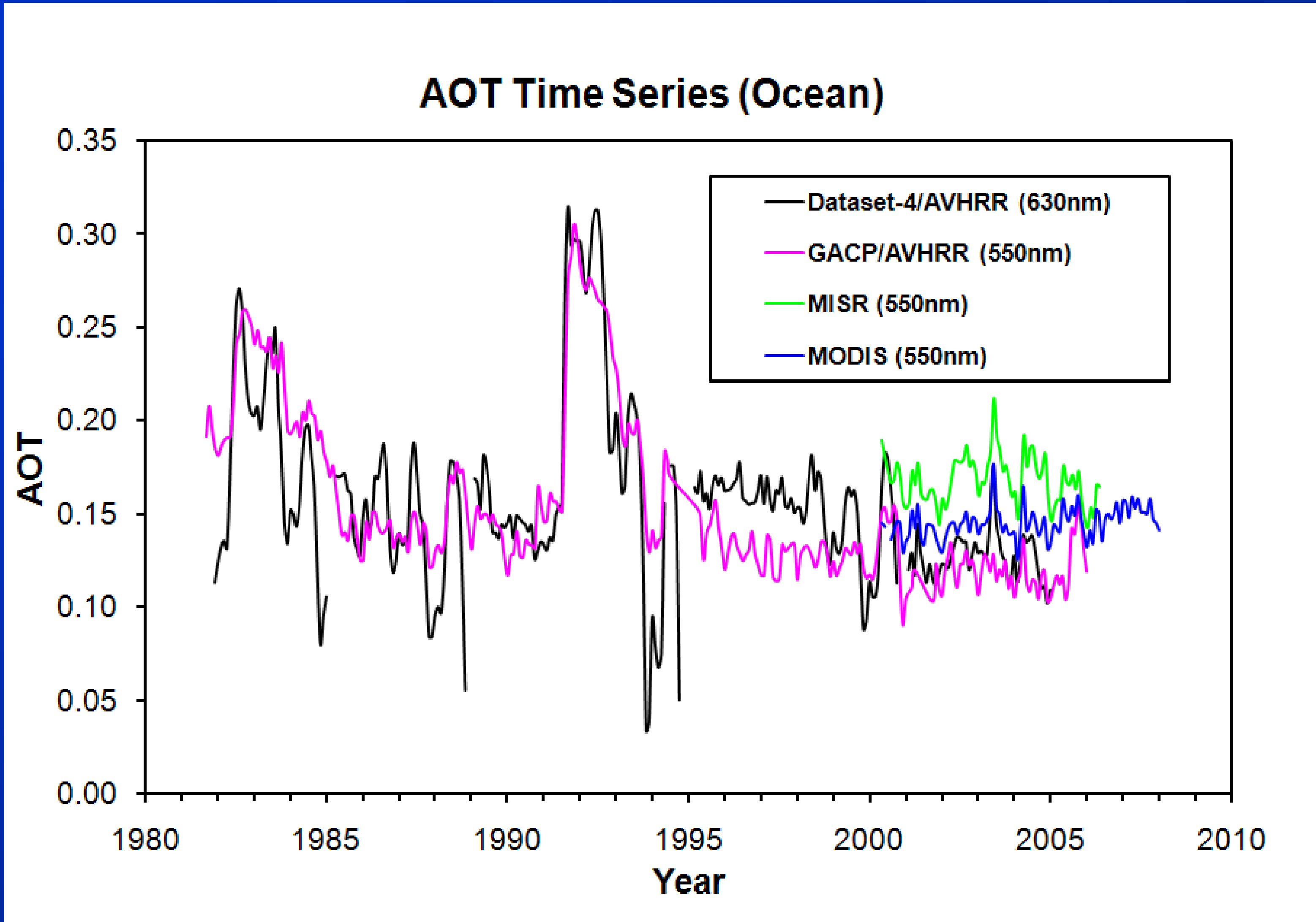
Case 2 (Dataset 4 & 5 Comparison):

Effect of aerosol retrieval algorithm on AOT trend (revised two-channel versus one-channel algorithm).

Case 3 (Dataset 1 & 5 Comparison):

Effect of calibration on AOT trend (SNO versus no-SNO).

Examples of AOT Time-Series



AOT Long-term Trend Analysis

Define Some Terminology:

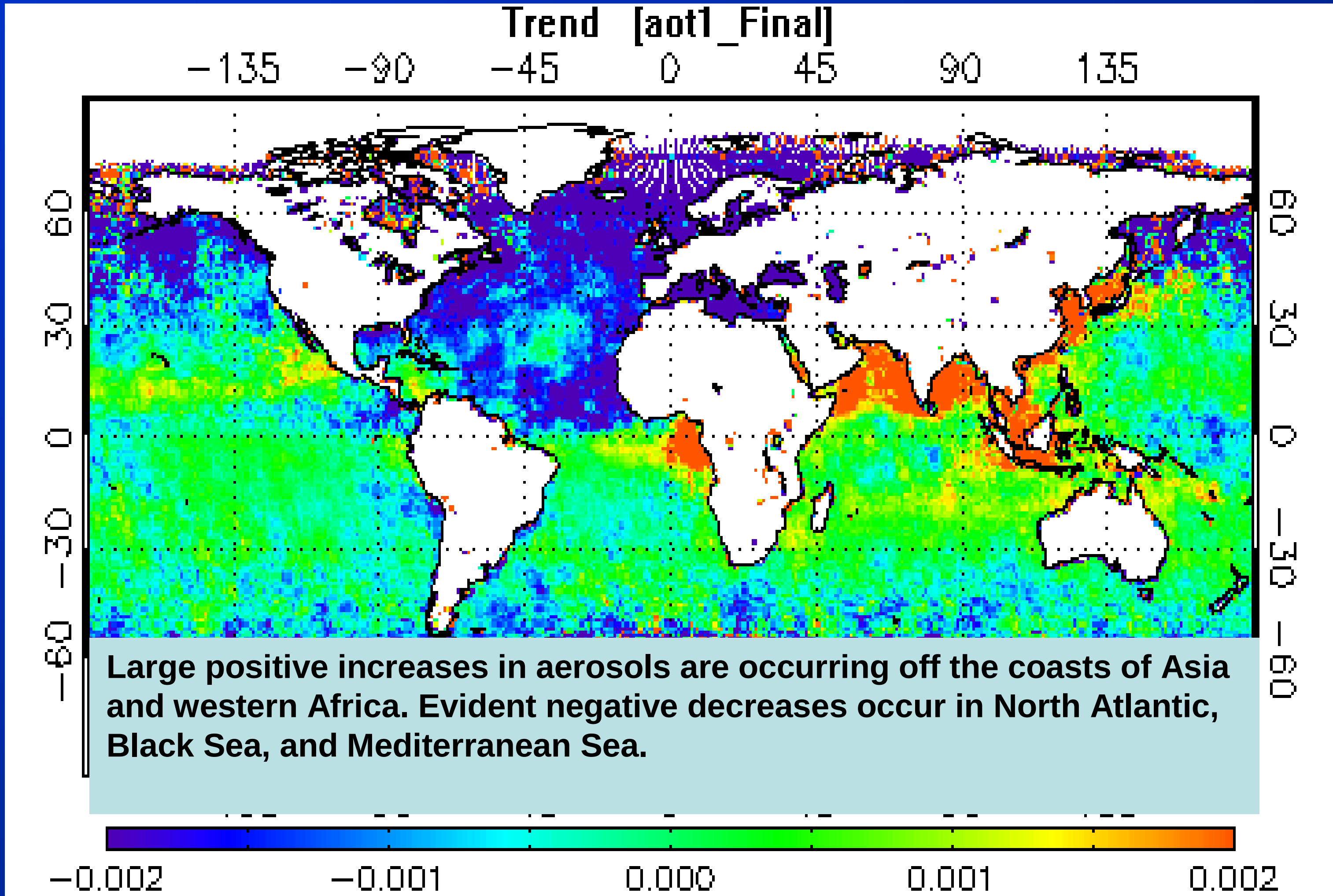
- **Linear long-term trend (LLT):**
  - The AOT LLT is the slope of linear regression line for the time series of monthly, or seasonally, or annually averaged AOT.
  - LLT is in the unit of absolute (or percentage) changes per decade or per year.

- **Significance of AOT LLT:**
  - Defined as LLT/σ, σ is the standard deviation of the AOT LLT.
  - Trend is examined at 95% confidence level (or 5% significance level), which is corresponding to LLT/ $\sigma \leq -2$ (negative trend) or LLT/$\sigma \geq 2$ (positive trend).

Global AOT Long-term Trend Map

AOT (0.63μm) LLT (1/year) over Ocean

(Reference Dataset 4)

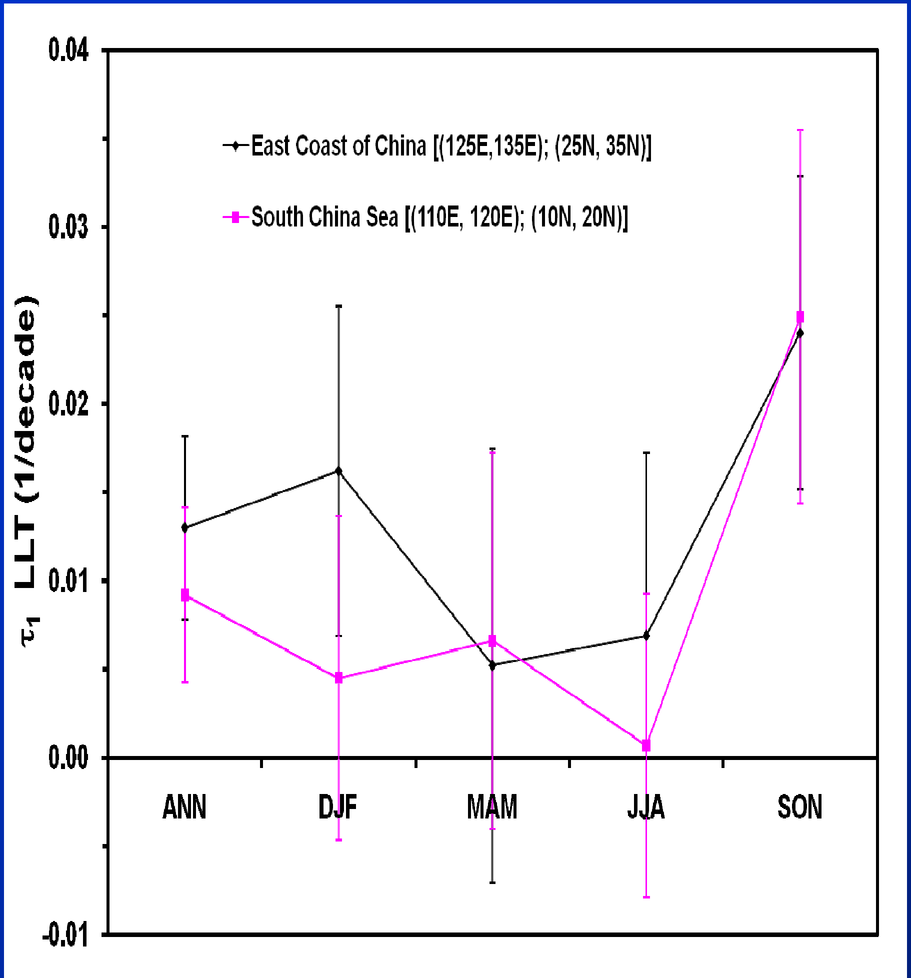


Large positive increases in aerosols are occurring off the coasts of Asia and western Africa. Evident negative decreases occur in North Atlantic, Black Sea, and Mediterranean Sea.

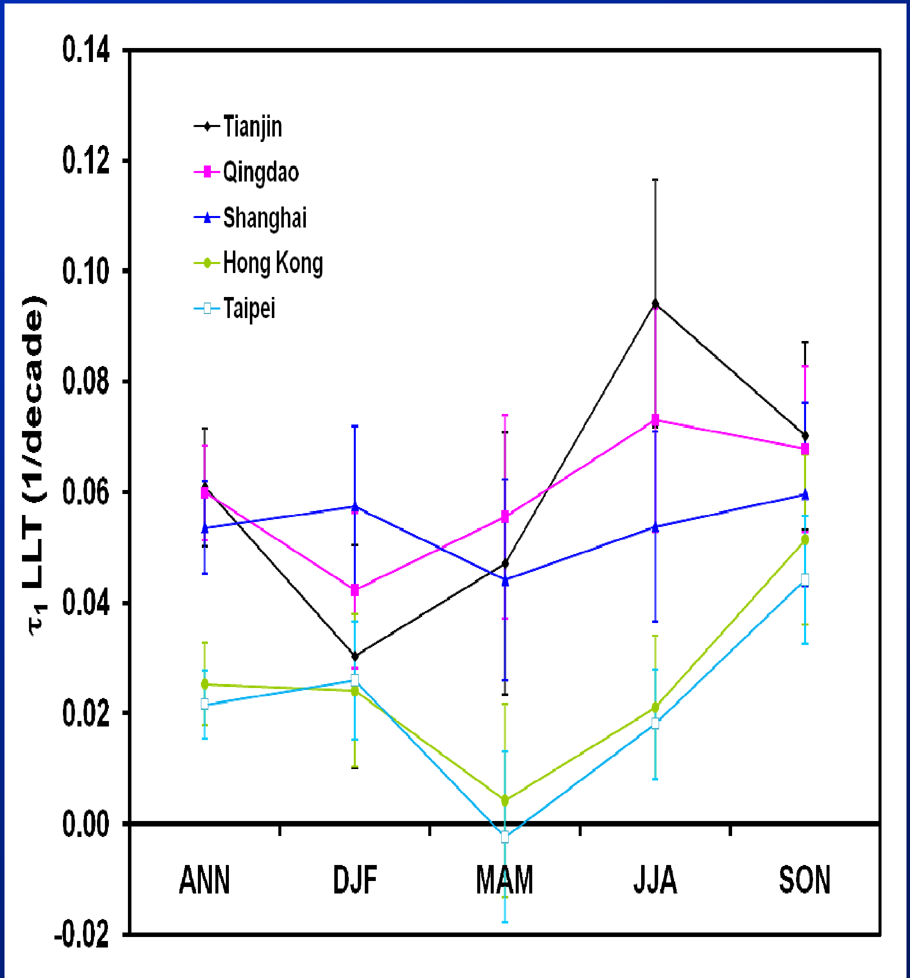
Seasonal Variations of LLT for Regional AOTs

(Fast Developing Regions)

Coast Areas of China

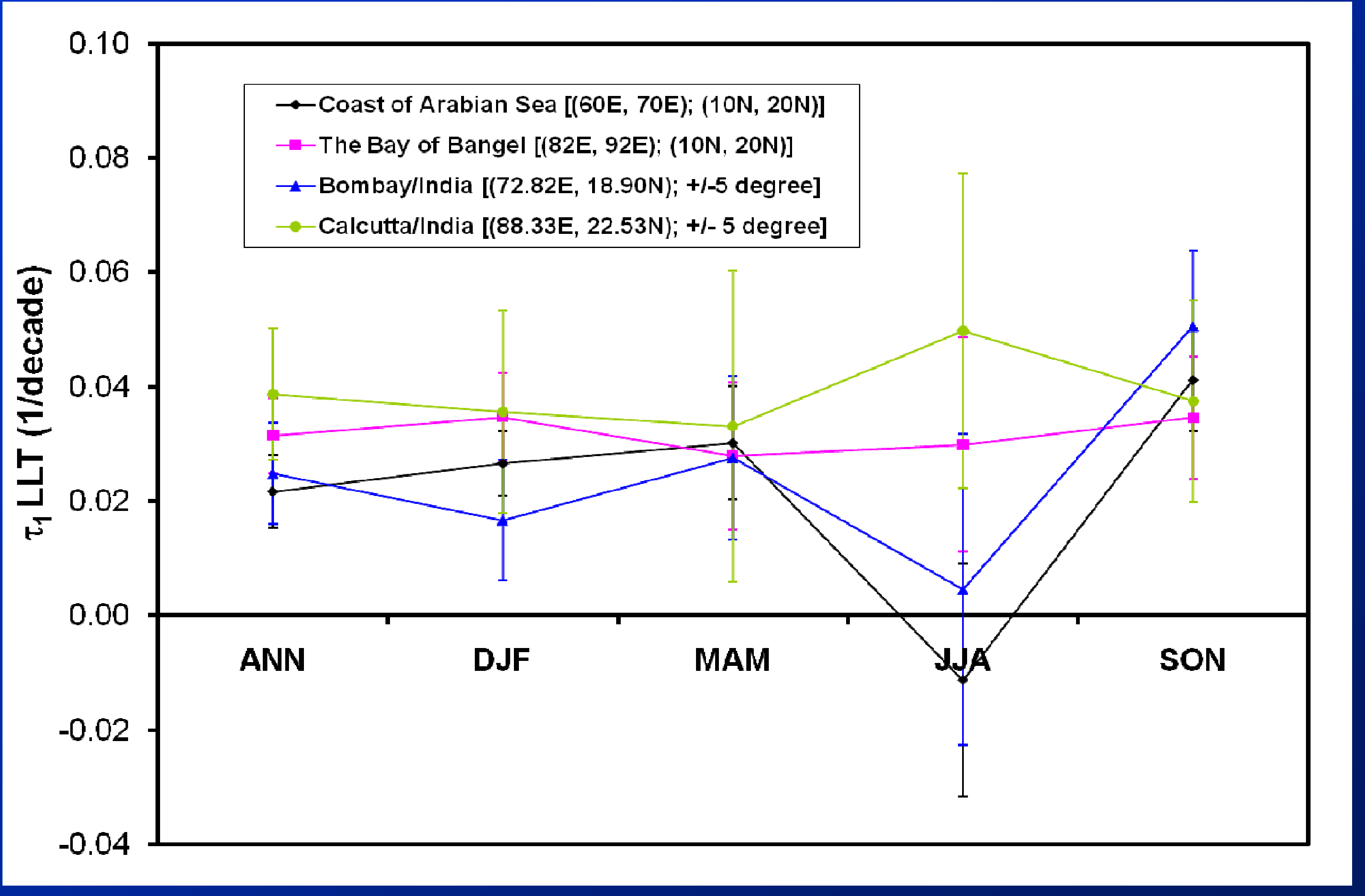


Surrounding Areas of Big Cities

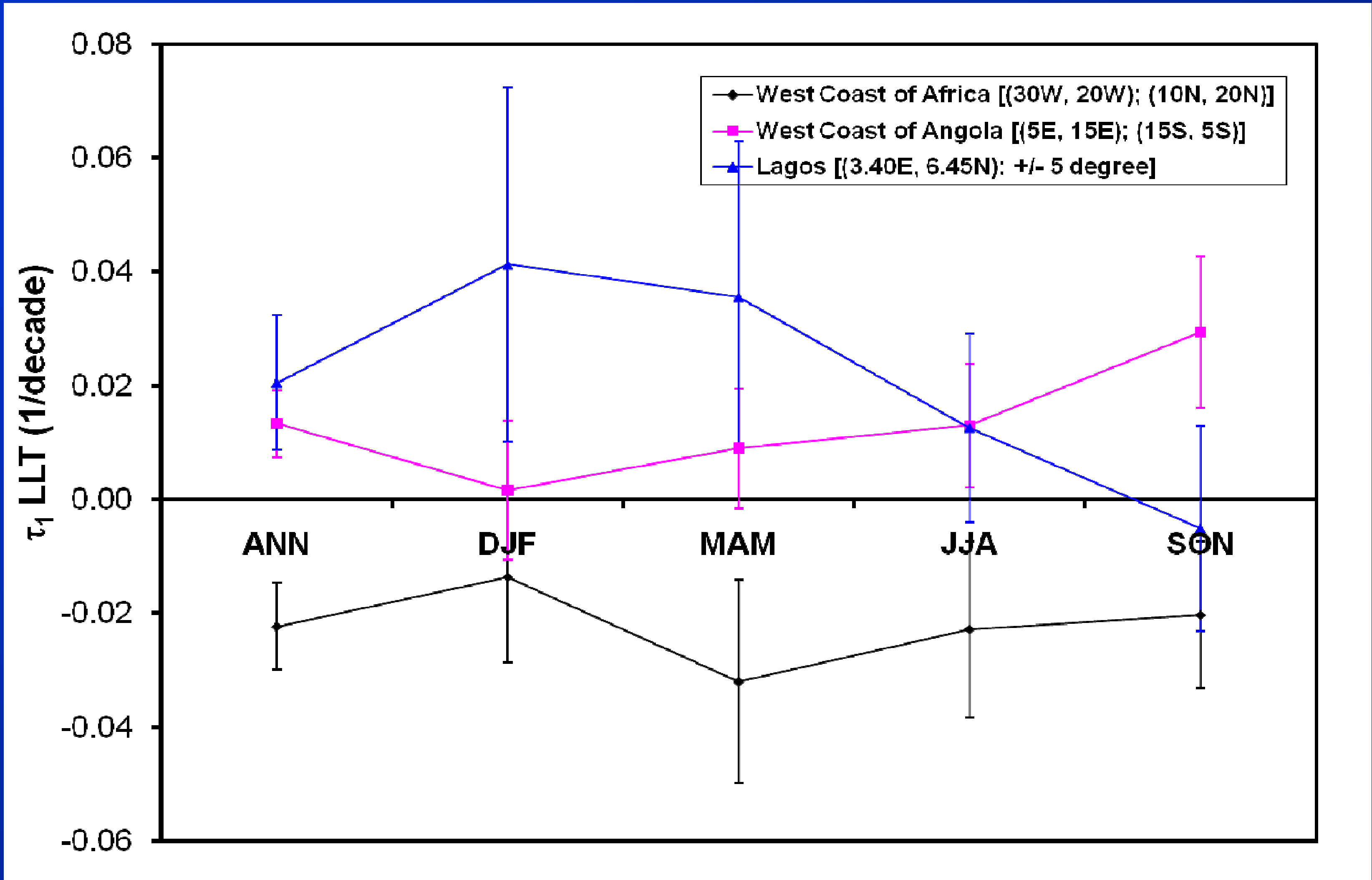


Seasonal Variations of LLT for Regional AOTs
(Fast Developing Regions)

Coast areas of Arabian Sea and Bay of Bengal



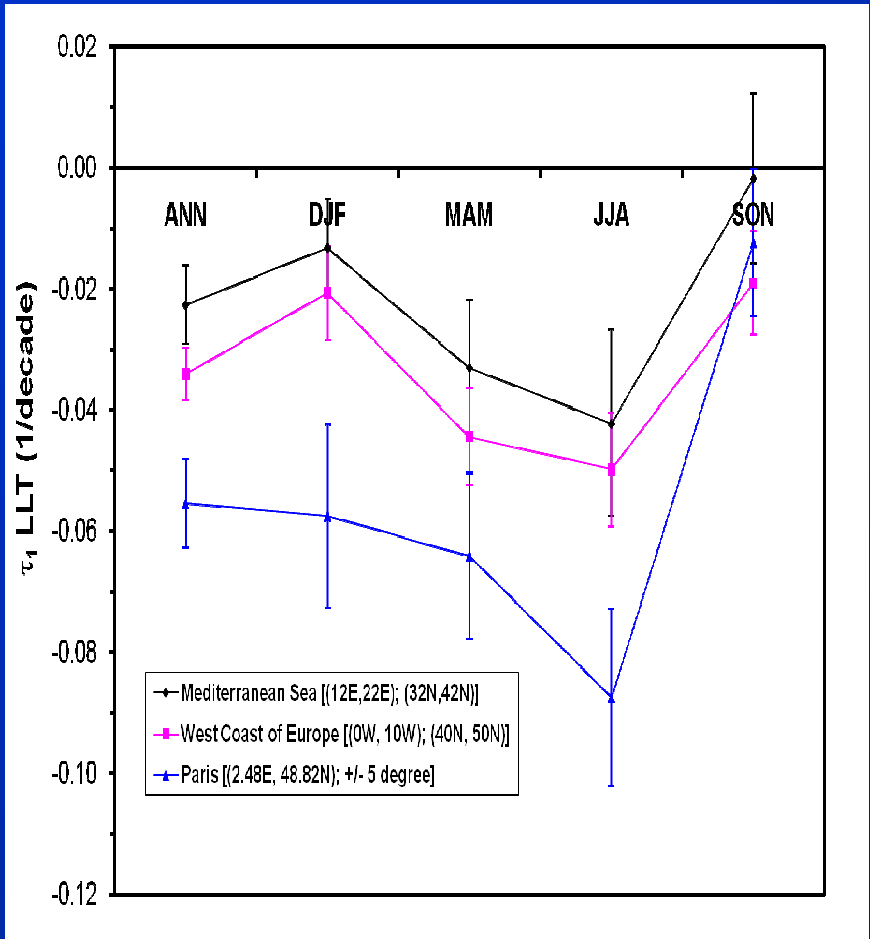
Seasonal Variations of LLT for Regional AOTs
(Dust and Biomass Burning Regions)



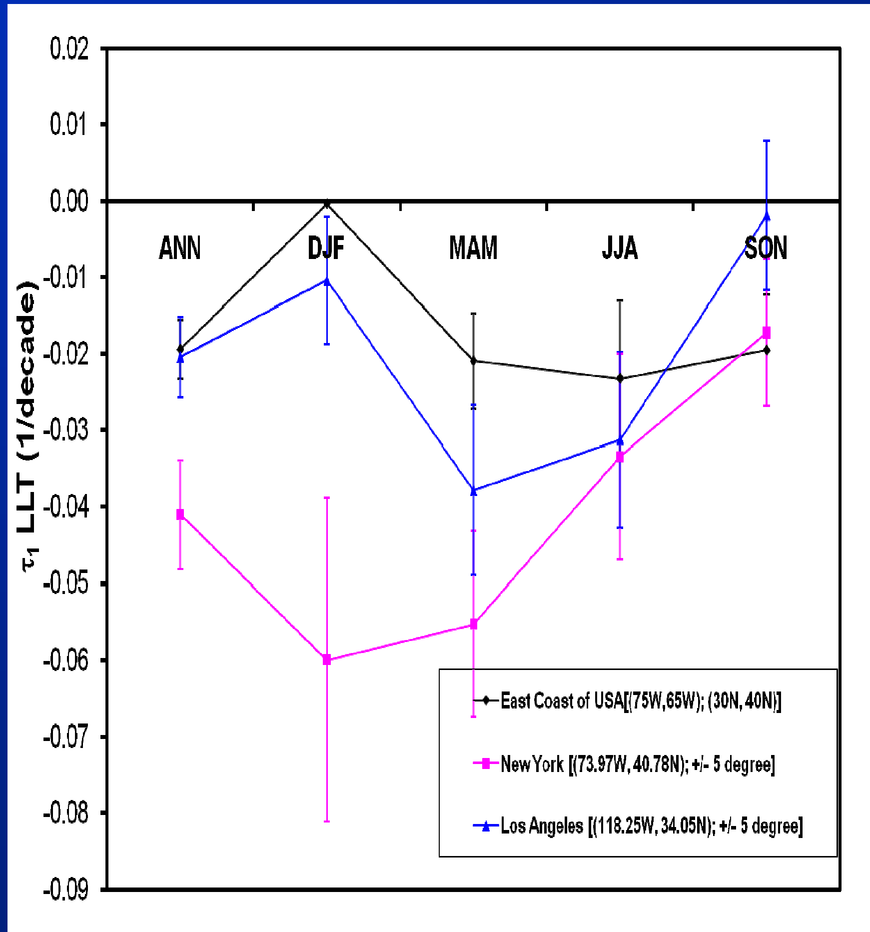
Seasonal Variations of LLT for Regional AOTs

(Industrialized Regions)

Europe

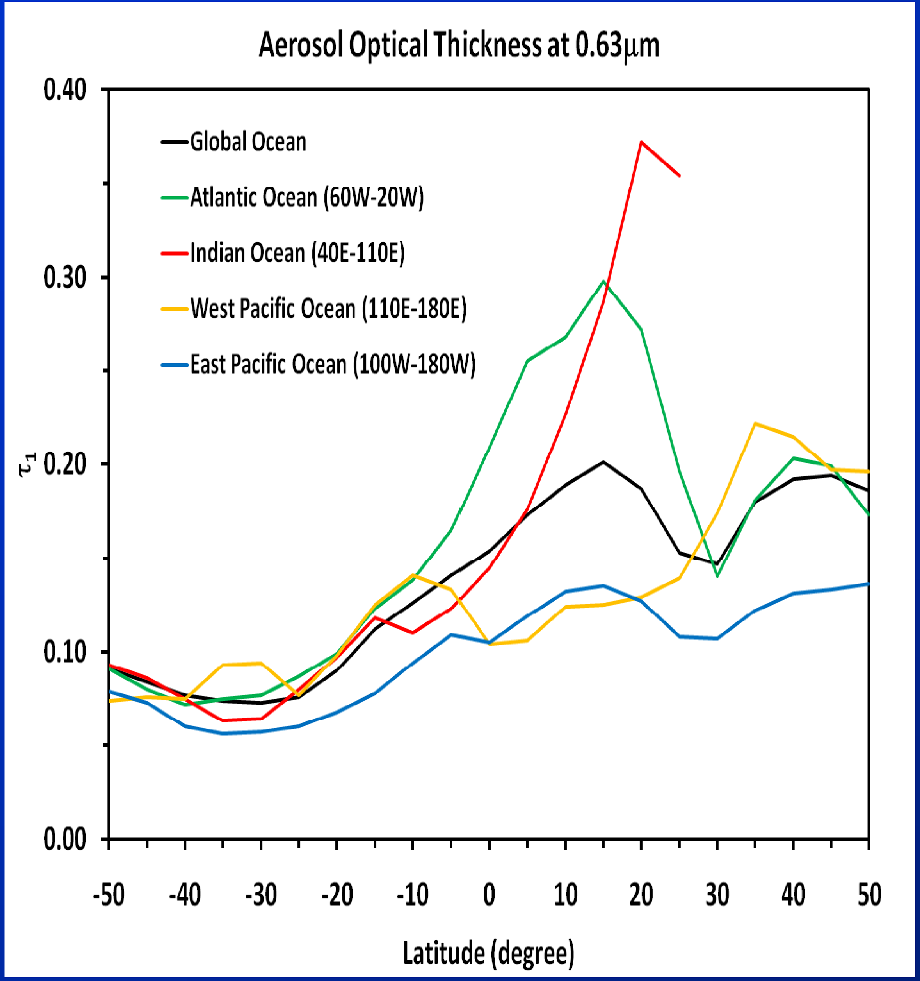


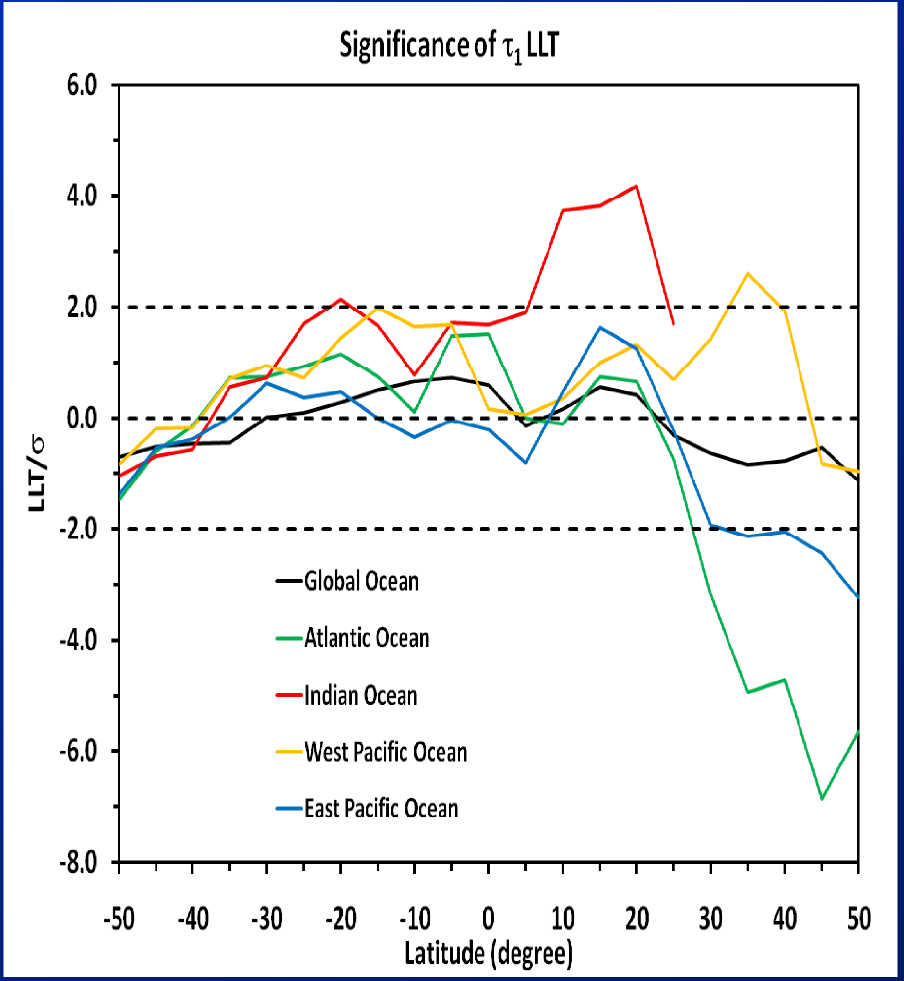
North America



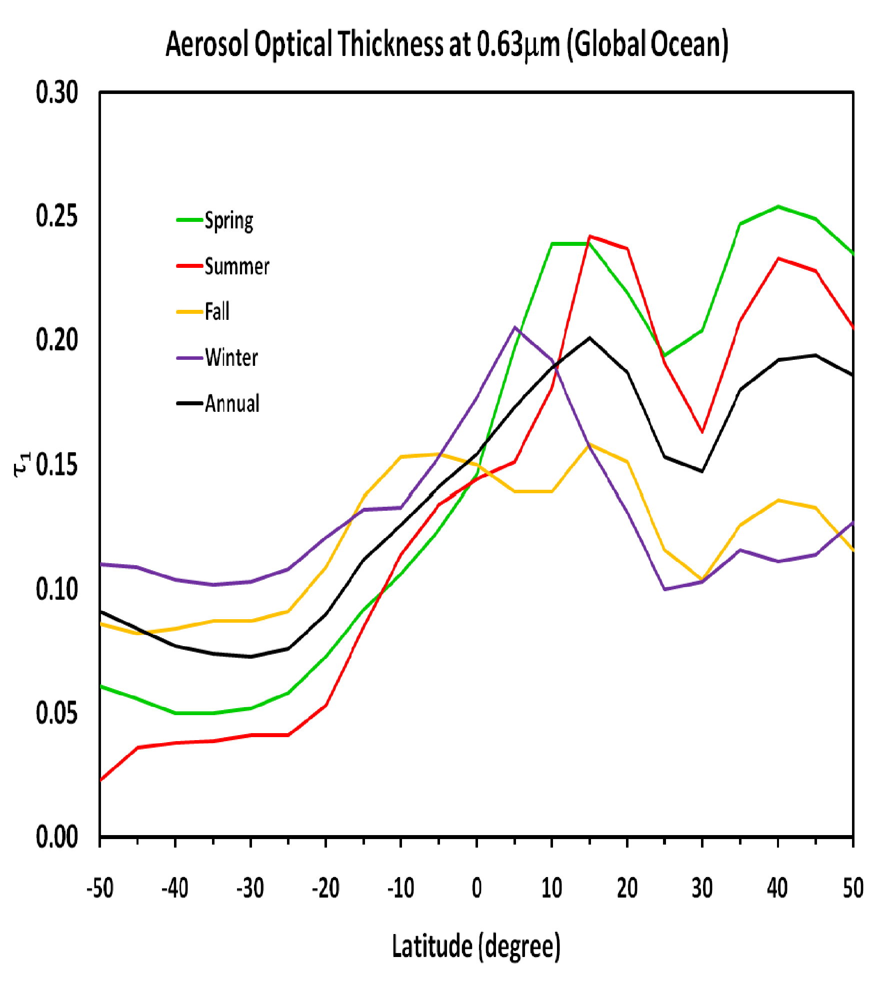
AOT Zonal Trend

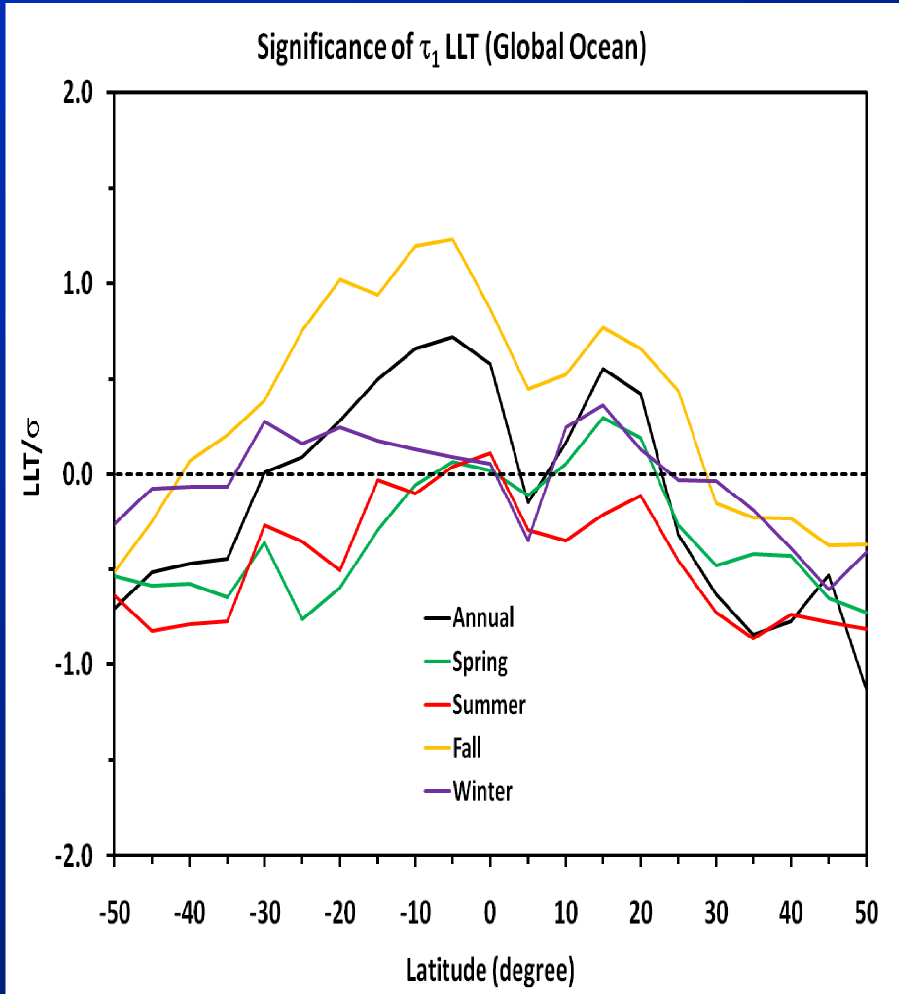
Latitudinal-Distribution



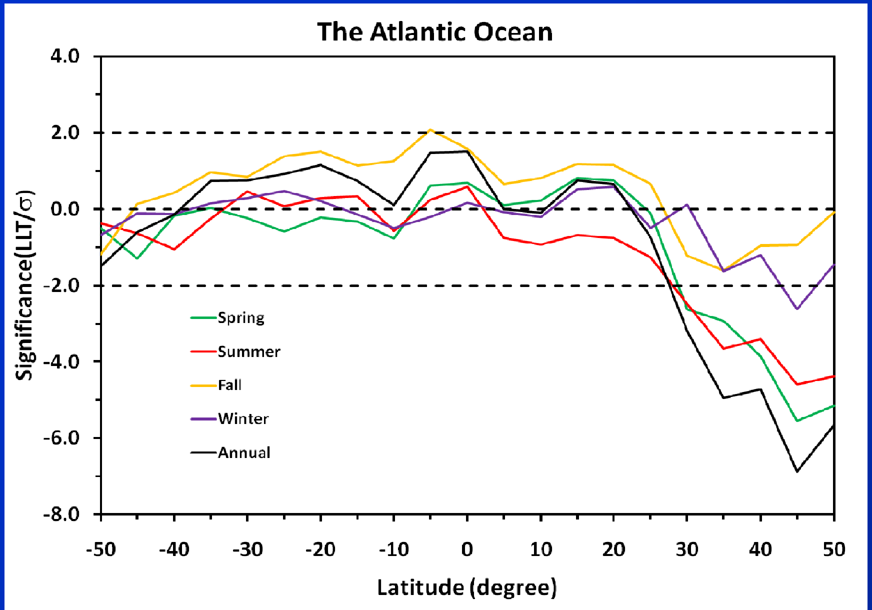


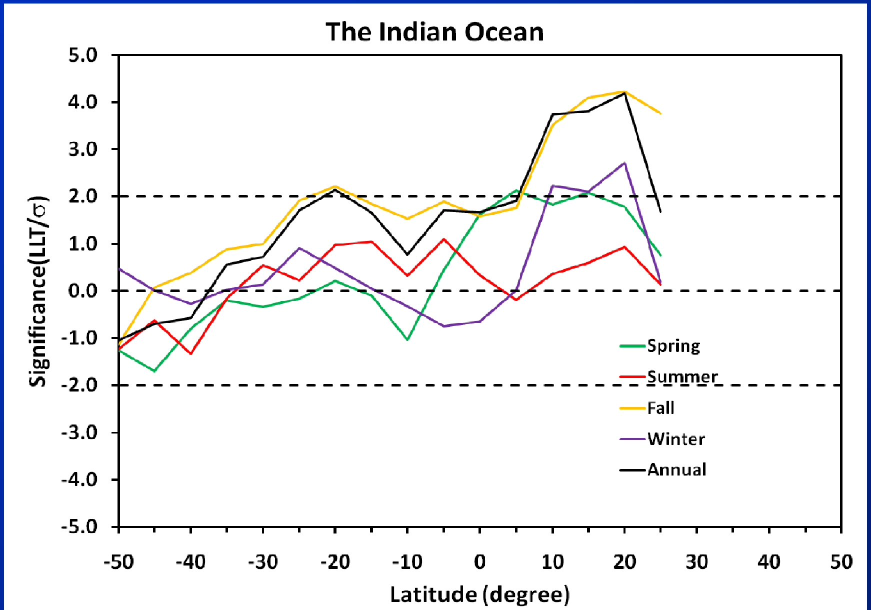
Seasonal Variations of Zonal Distribution
(Global Ocean)

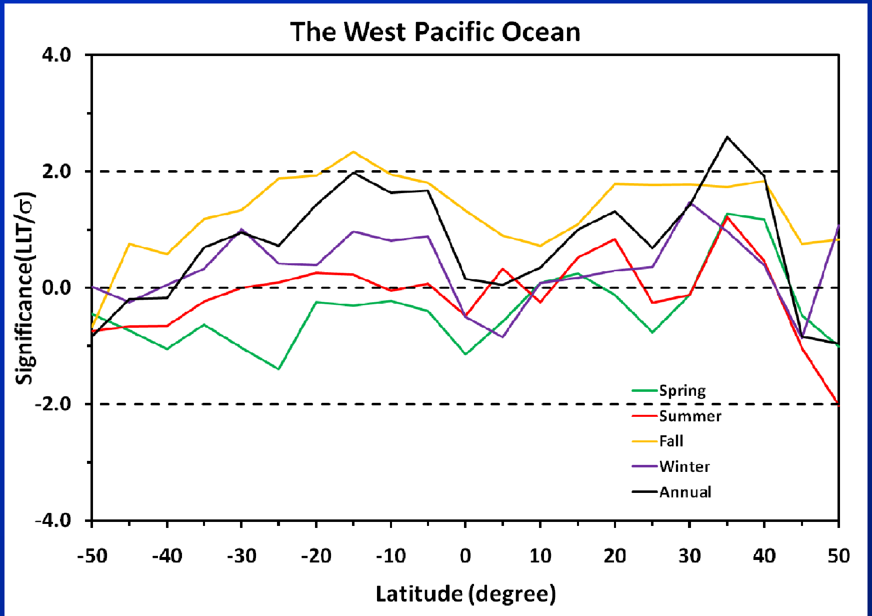


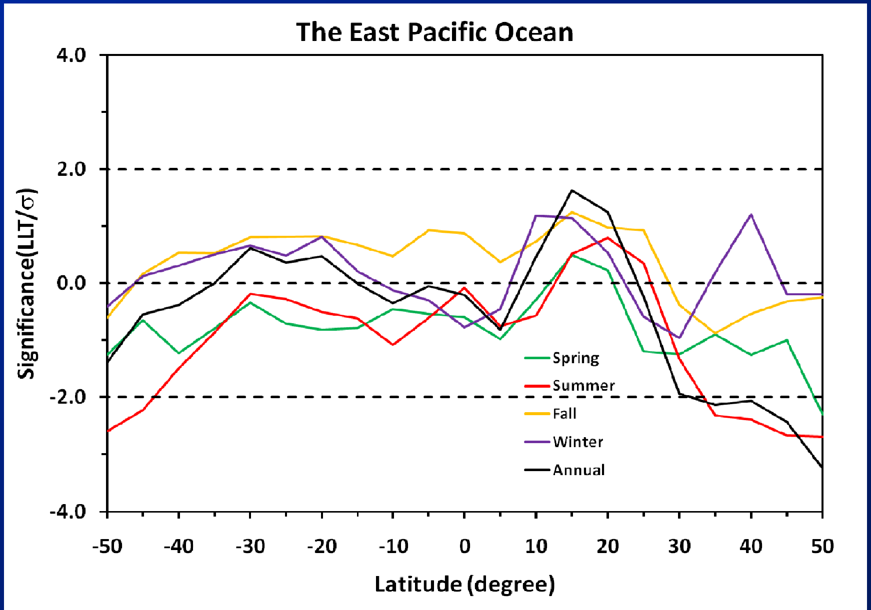


Seasonal Variations of Trend Zonal Distribution









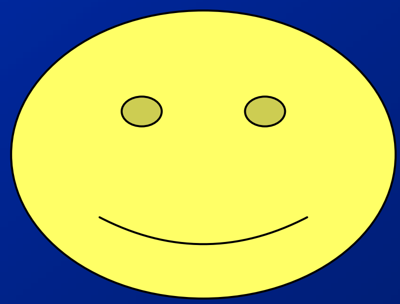
Summary and Conclusions

- Nearly 29-years of AOT CDR from AVHRR observations over the global ocean has been generated and used to study the AOT LLT in order to support the study of SSR decadal variations.
- Regions influenced by industrial pollutions from fast developing countries (e.g., China, India), AOT is in positive trend and clear-sky solar dimming is anticipated.
- Regions influenced by industrial pollutions from developed countries in Europe and North America, AOT is in negative trend and clear-sky solar brightening is anticipated.
- Regions influenced by Saharan dust, AOT is in negative trend. However, Regions influenced by Safari biomass burning, AOT is in positive trend.
- For the LLT of zonally averaged AOT over the global ocean, their significance generally falls below 95% confidence level.
- However, for the Atlantic Ocean (AO), Indian Ocean (IO), and West Pacific Ocean (WPO), their LLT of zonal mean AOT can easily pass 95% confidence level in some latitudes belts (e.g., 5-25^{o}N for IO, 33-40^{o}N for WPO, 30-50^{o}N for AO). Zonally averaged solar dimming/brightening is anticipated accordingly in clear-sky conditions.

Acknowledgement

- **Funding Support:**
  Climate Data Record (CDR) Program at NOAA/NESDIS/NCDC

Thank You!



Backup Slides

NOAA/NESDIS AVHRR Aerosol Retrieval Algorithm

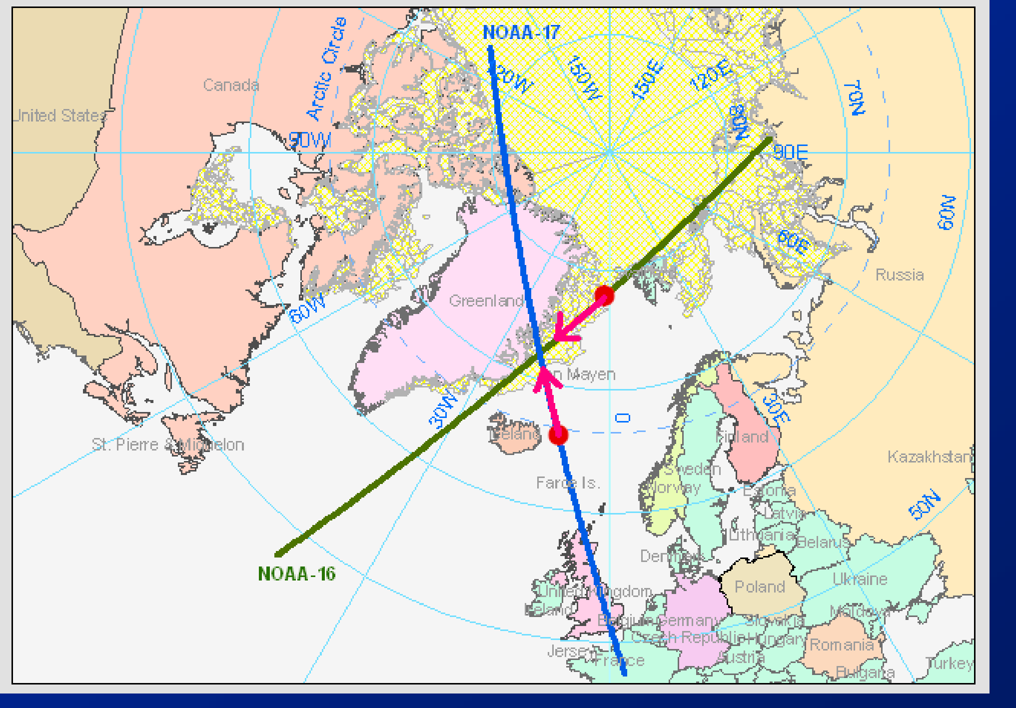
Algorithm (Ocean)	AOT Products	Description
one channel [Stowe et al., 1997]	τ_1 (0.63μm) (PATMOS)	One-mode lognormal size distribution; no absorption; lambertian surface with diffuse glint correction.
independent two channel [Ignatov & Stowe, 2002]	τ_1 (0.63μm) τ_2 (0.83μm) (PATMOS-x)	Ono-mode lognormal size distribution; no absorption; ocean surface BRDF (V=1m/s); tuned to match the one-channel retrieval.
revised independent two channel [Zhao et al., 2004]	τ_1 (0.63μm) τ_2 (0.83μm) (PATMOS-x based new data)	Bi-mode lognormal size distribution; weak absorption; ocean surface BRDF (V=6m/s); adjusted according to the AERONET validation.

Simultaneous Nadir Overpass (SNO) Calibration

SNO Method [Cao et al., 2004; Heidinger et al., 2002]:

- Find the orbits of different satellites that have intersections.
- Use time and location information to determine simultaneity between two pixels.
- Use MODIS as reference to retrospectively recalibrate the AVHRR observations from all the NOAA/POES satellites.

Schematic View of the Overpass of Two NOAA Satellites

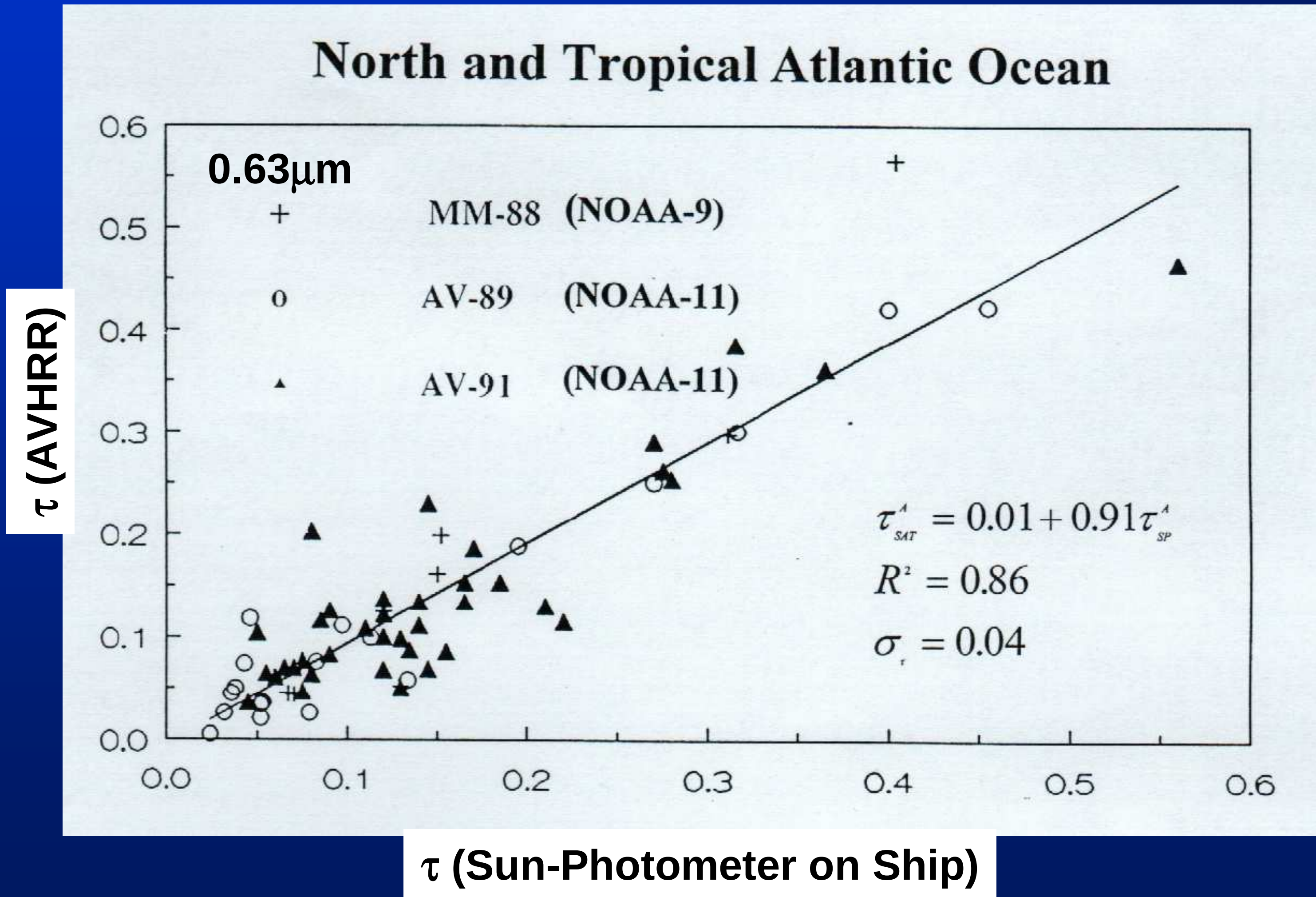


Benefits:

1. **AVHRR calibration is improved and its uncertainty become close to MODIS.**
2. **A consistent calibration is applied to all the AVHRR observations from different satellite platforms – critical for long-term trend detection.**

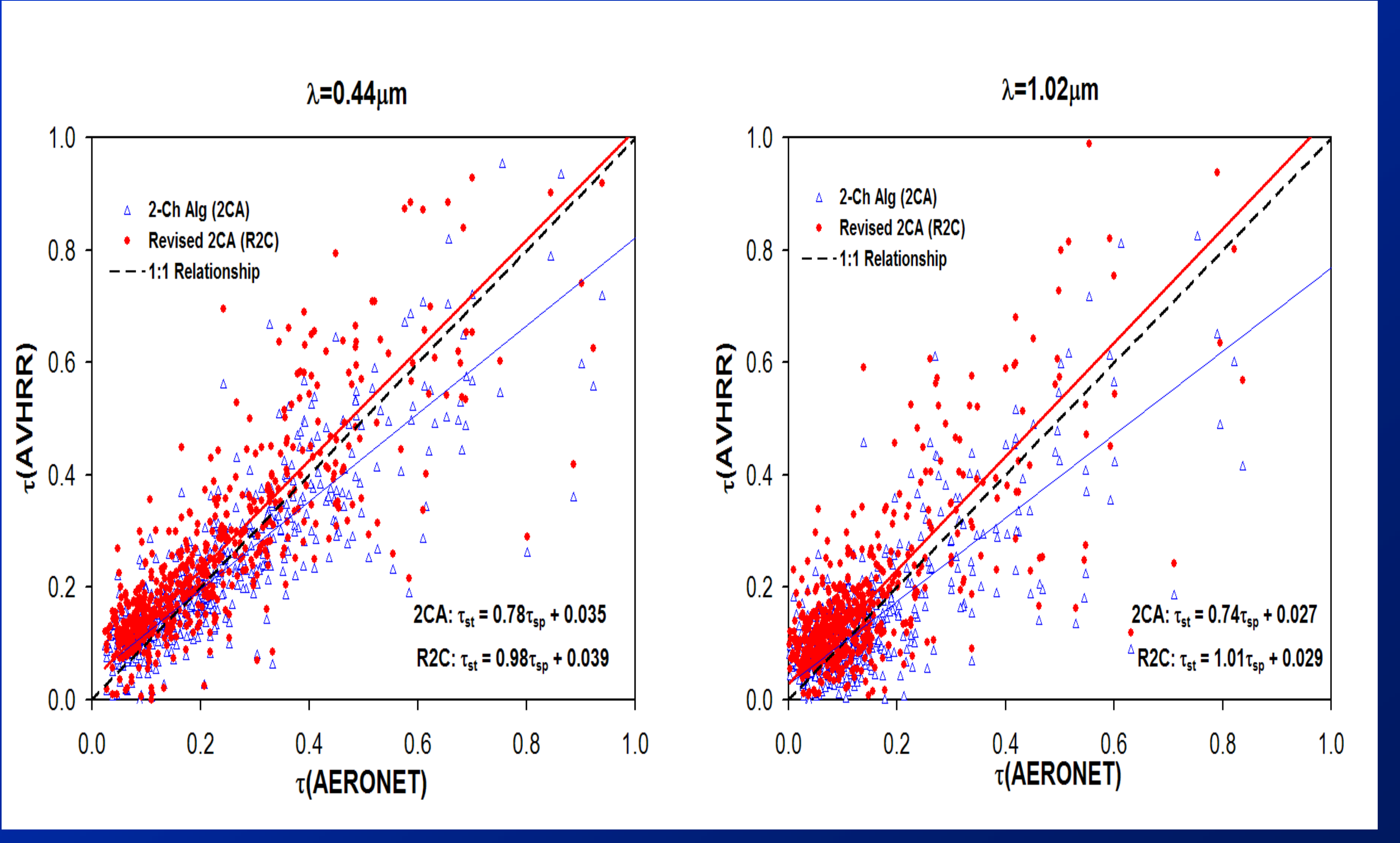
Validation of AVHHR Single Channel Algorithm

(Stowe et al., 1997; JGR)



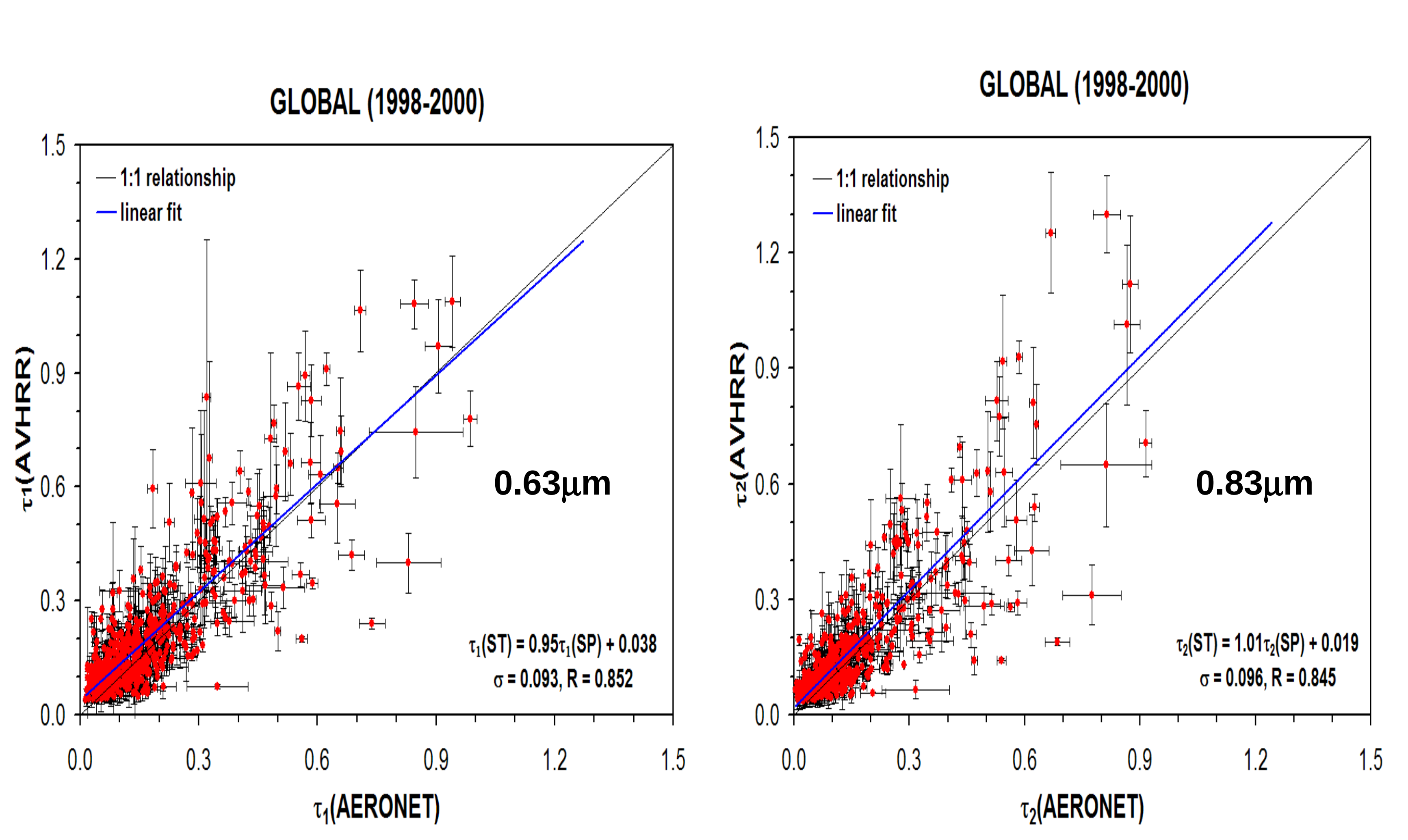
Validation of AVHRR Two Channel Algorithm and Revised Two Channel Algorithm

(Zhao et al., 2004; JGR)



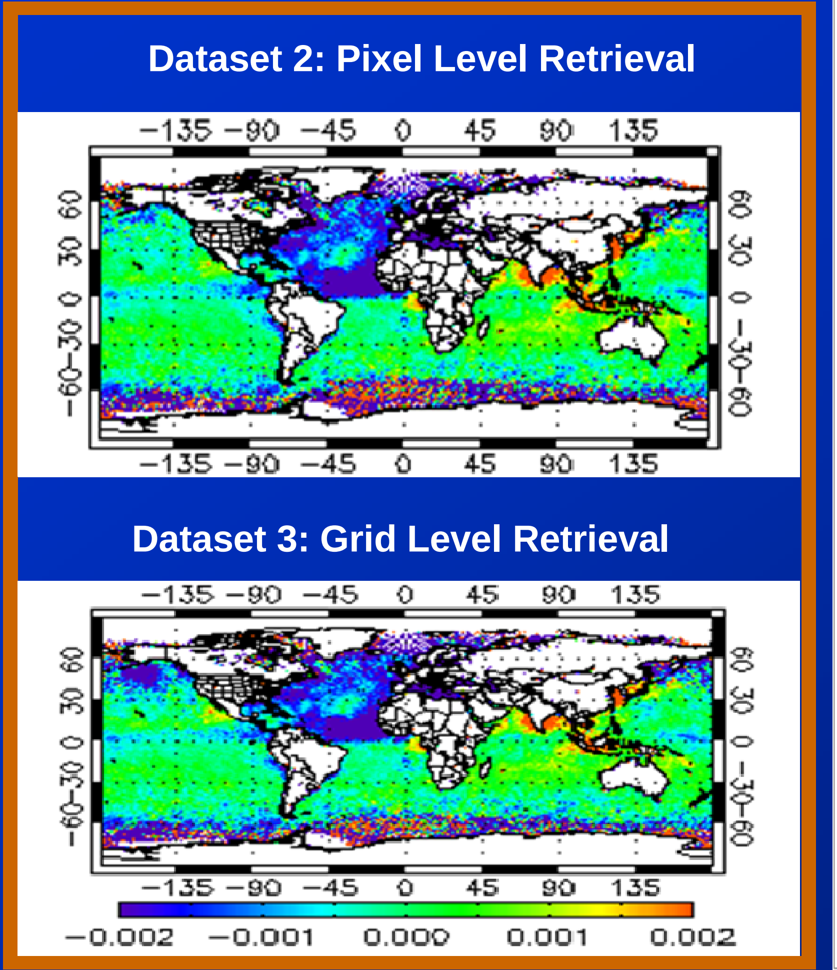
Validation of Revised AVHRR Two Channel Algorithm

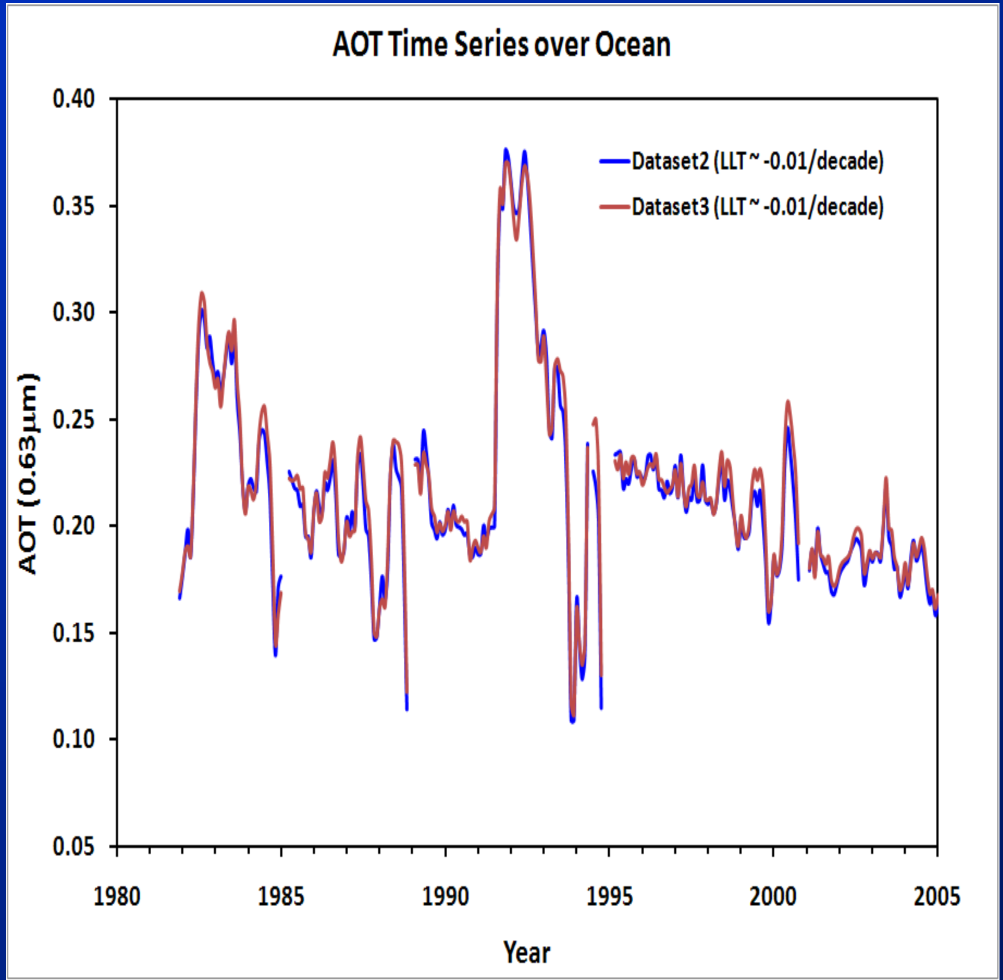
(Zhao et al., 2004)



Results of the Sensitivity Studies

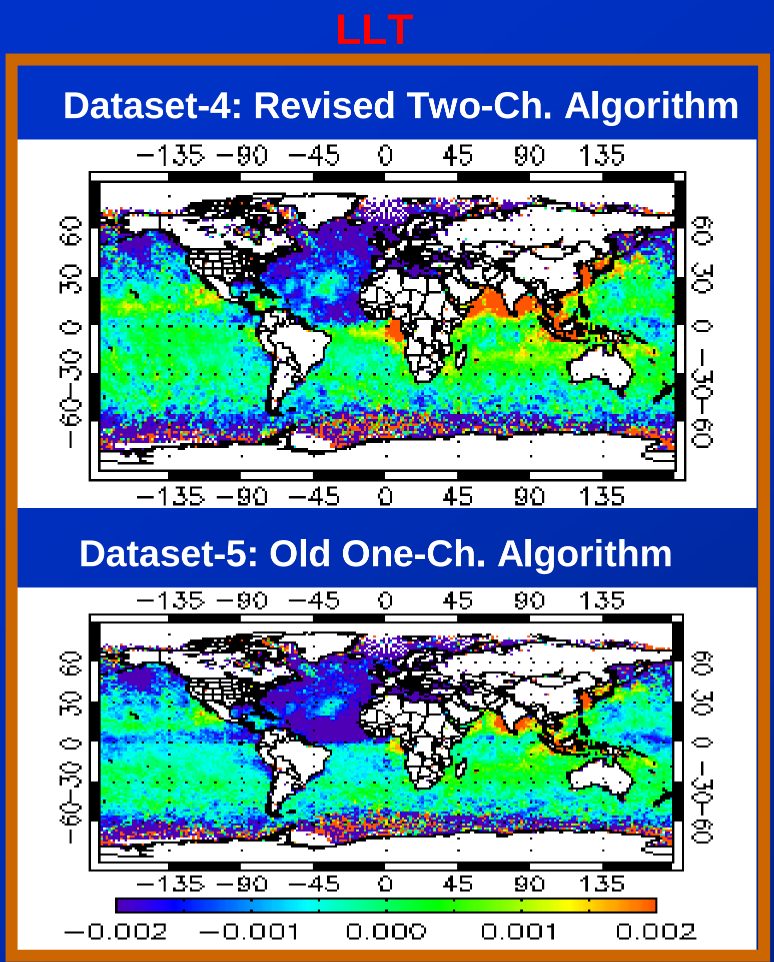
LLT Case 1 - Effect of Spatial Resolution

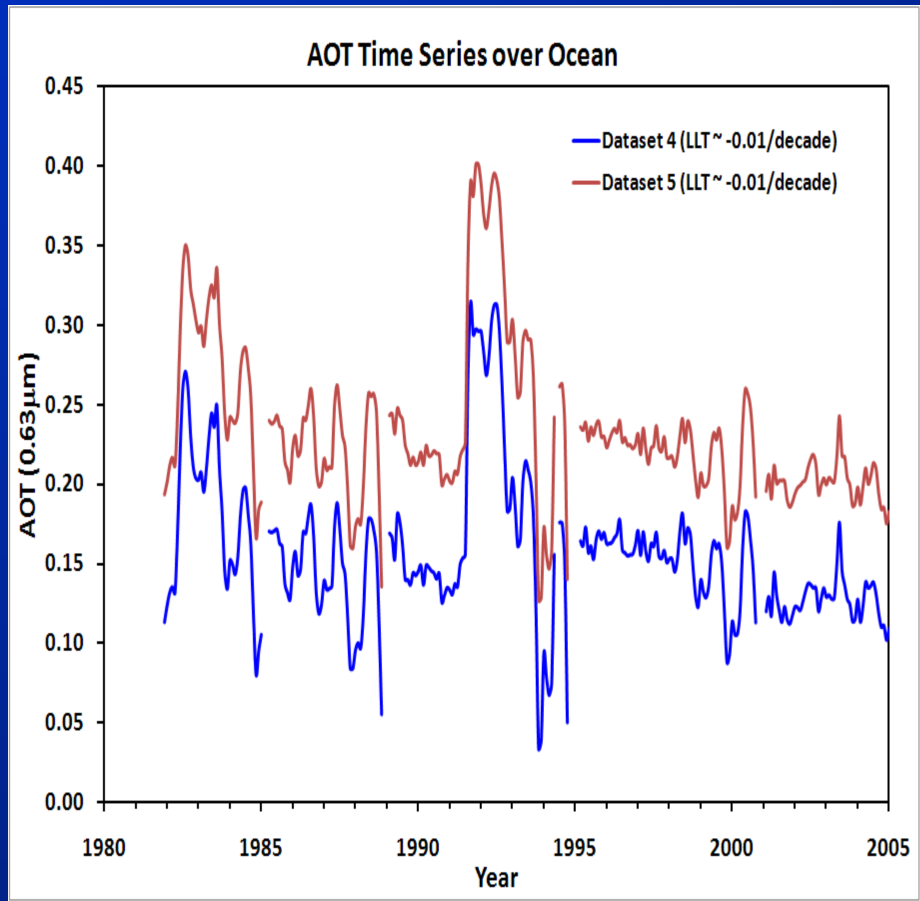




Conclusion: The difference in monthly averaged AOT LLT between the pixel and grid level retrieval can be neglected. Grid level retrieval is good for efficient re-processing.

Case 2 - Effect of Aerosol Retrieval Algorithm



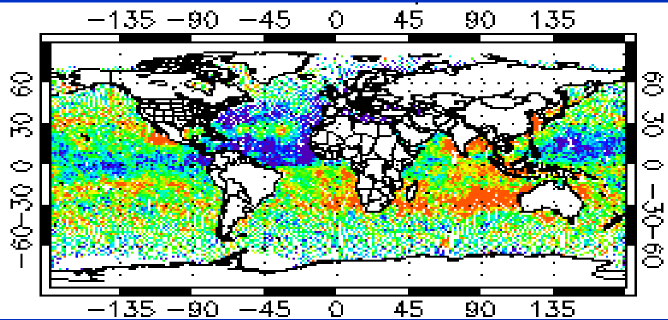


Conclusions: 1) Global monthly mean AOTs of Dataset-4 are lower than Dataset-5. 2) Difference in the LLT are mainly in the regions under the influence of industrial and biomass burning pollutions and desert particles. 3) However, the algorithm effect on the LLT of global monthly averaged AOT can still be neglected.

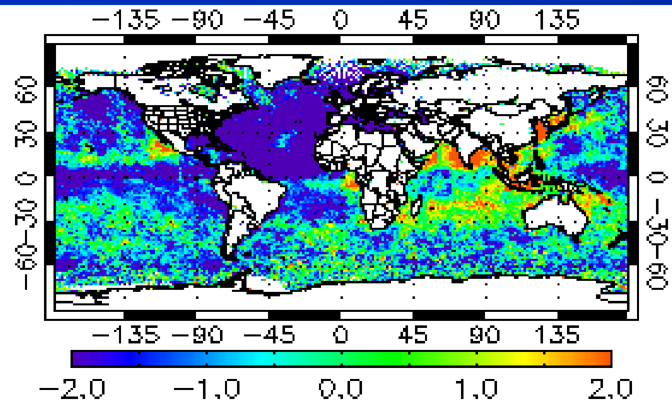
Case 3 - Effect of Calibration

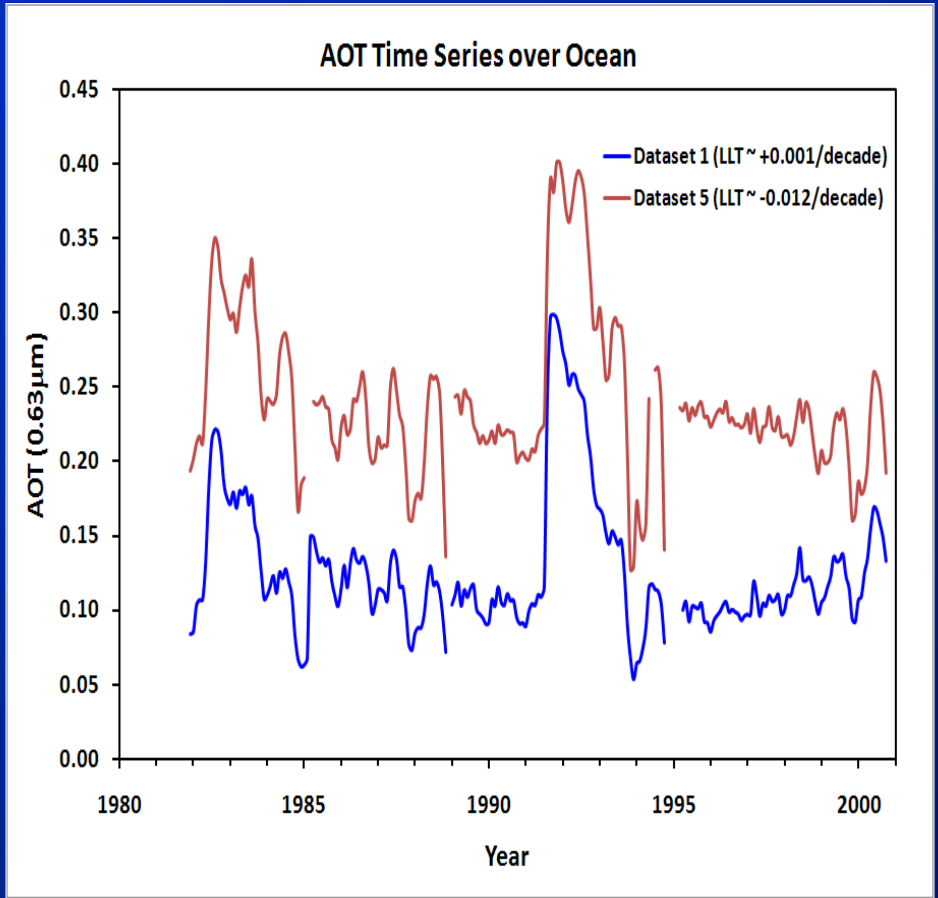
Significance of LLT

Dataset-1: Old Calibration



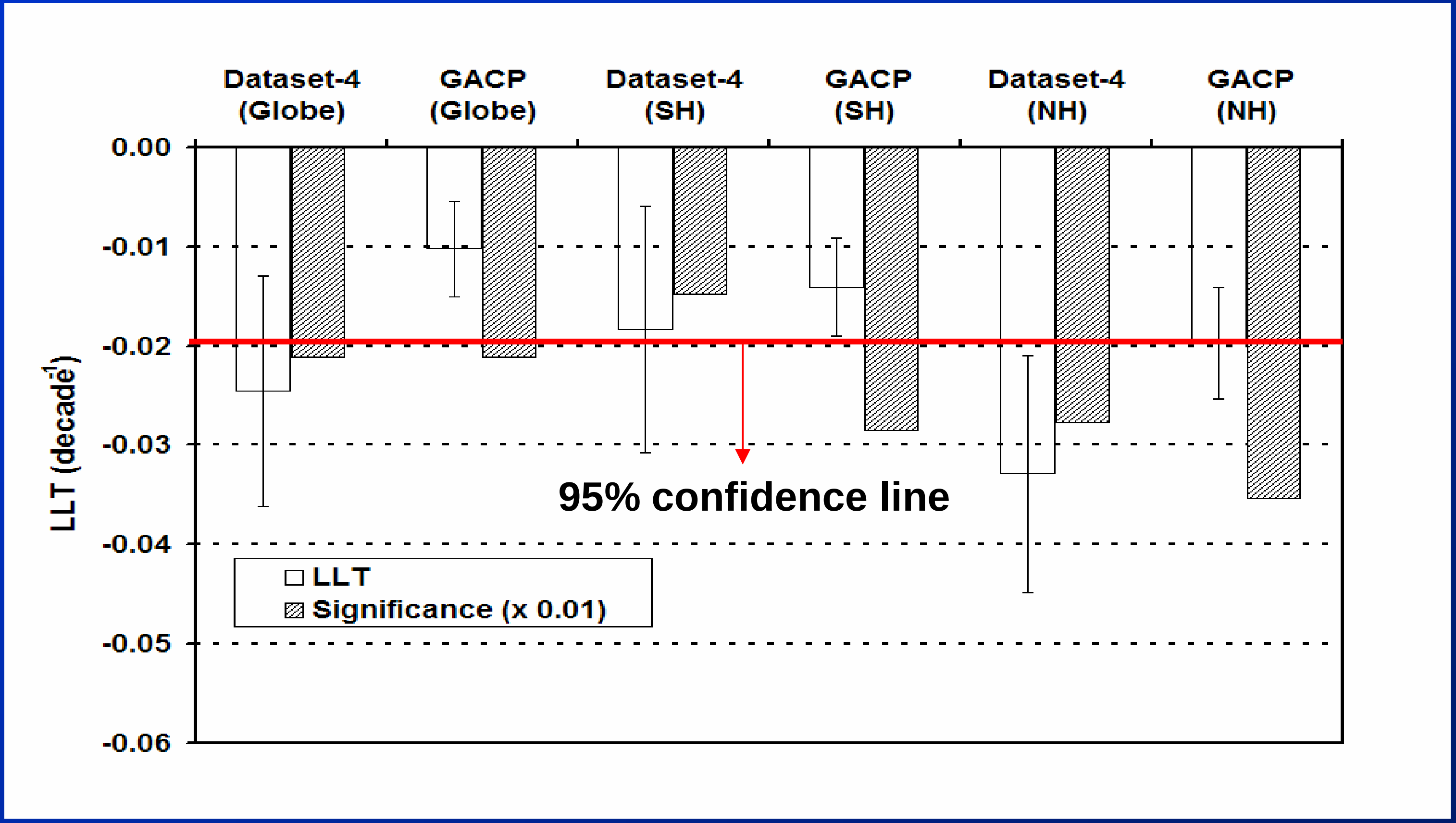
Dataset-5: New SNO Calibration





Conclusions: **1) Global monthly mean AOT with new SNO calibration is higher than that without SNO calibration; 2) The effect of calibration on the AOT LLT is more evident over broad open oceans; 3) The calibration effect on the LLT of global monthly averaged AOT can change the sign of the trend.**

Comparison of LLT and the Corresponding Significance for the Annual Mean AOT between Dataset-4 and the GACP Data

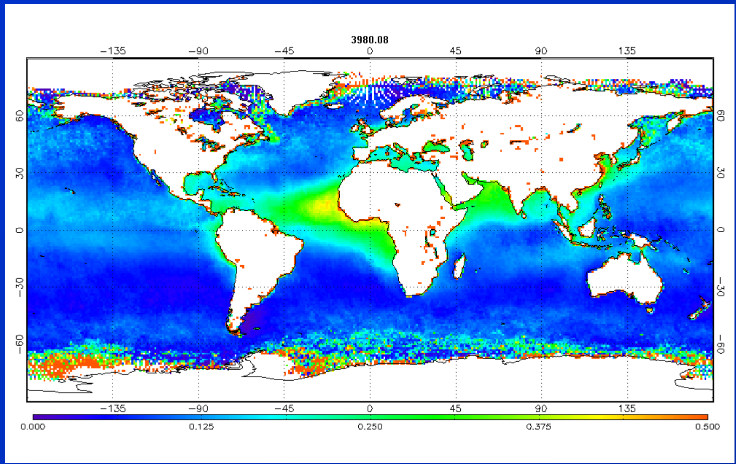


Two AVHRR AOT retrievals with independent calibration, cloud screening, and retrieval algorithm give a consistent negative sign of tendency in global averaged AOT but their magnitude is somewhat different.

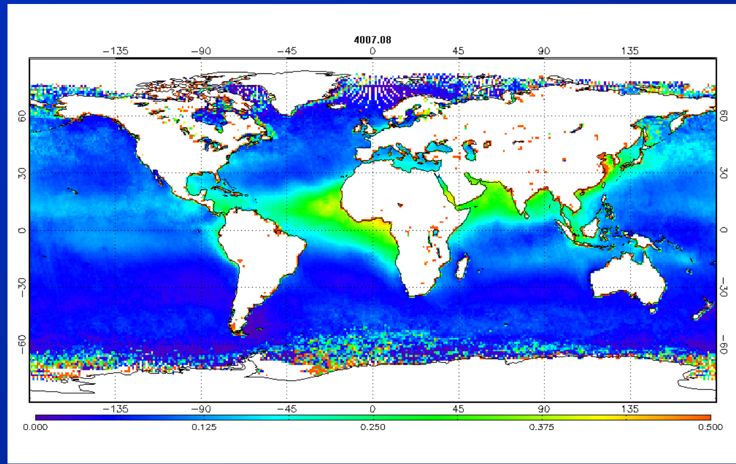
Comparison of Two AVHRR-Based Aerosol Products – Dataset 4 vs GACP

(Average AOT for Two Quiescent Periods of Volcano)

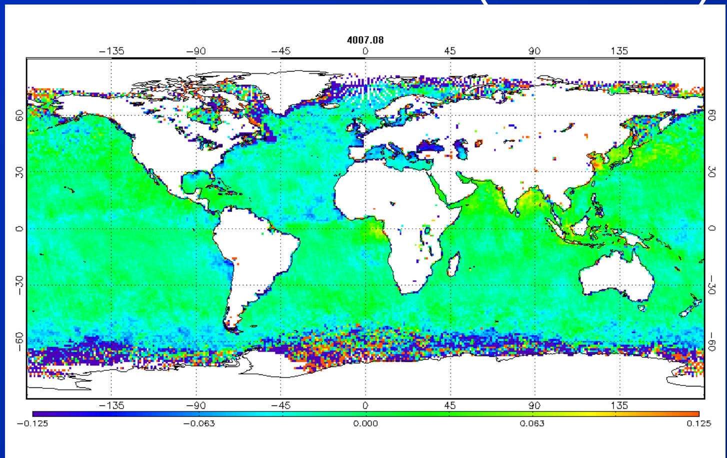
Period 1: Jul 1988-Jun 1991



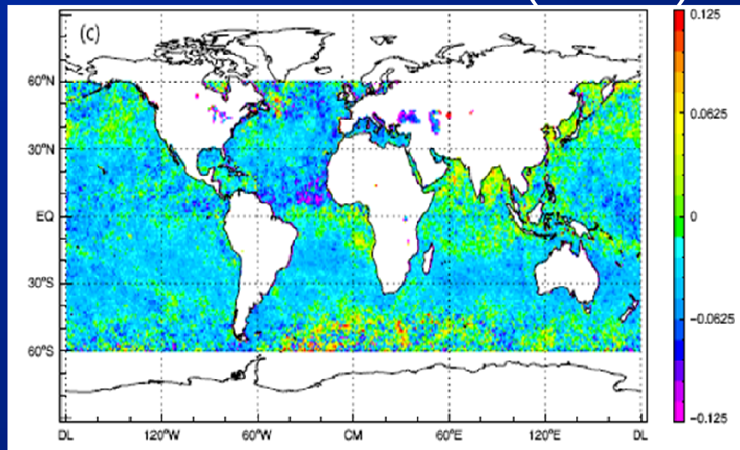
Period 2: Jan 2002-Dec 2004



Period 2-1 Difference (Dataset 4)



Period 2-1 Difference (GACP)



<u>Both data show in period 2:</u>

1) decrease of AOT over the North Atlantic; 2) significant decrease over the Black Sea; 3) increase over the South, South-East, and East coast of Asia.